moisture in excess of that absorbed by the silt that causes changes in volume. Sands of equal surface area but containing different percentages of silt will bulk differently for the same percentage additions of water up to nearly the point of maximum bulking. At that point the variable effect of different silt contents is compensated for.

Experiments were also carried out upon sands having particles of uniform size. These sands were all prepared from one material by sieving it into its different sizes. Volume-moisture studies were then made on each size. These experiments also showed maximum bulking to be related to surface area. But it was found that this relation did not follow the same law as with graded aggregates. It was found that sands coarser than that passing the No. 6 sieve did not increase in volume with additions of moisture. It is thought that the reason for this is that the weight of the particles in these large sizes is sufficient to overcome the separating effect of the film of water surrounding the moistened particle. This explanation has not as yet been tested out experimentally.

Fig. 5 shows the relation between maximum bulking and surface area for these "one-size" sands. This relation is expressed by the equation

$$x = 0.30\ A^{0.612} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where x = increase in volume in per cent. and A = surface area in square feet per 100 lbs.

A few experiments were made with mixtures of sand and gravel. Only one sand and one gravel were used, but these were mixed in different proportions. Here also a relation between bulking and surface area was found. Successive additions of gravel decreased the percentage of maximum bulking in the same ratio as it decreased the surface area. Fig. 6 illustrates the results of these few tests.

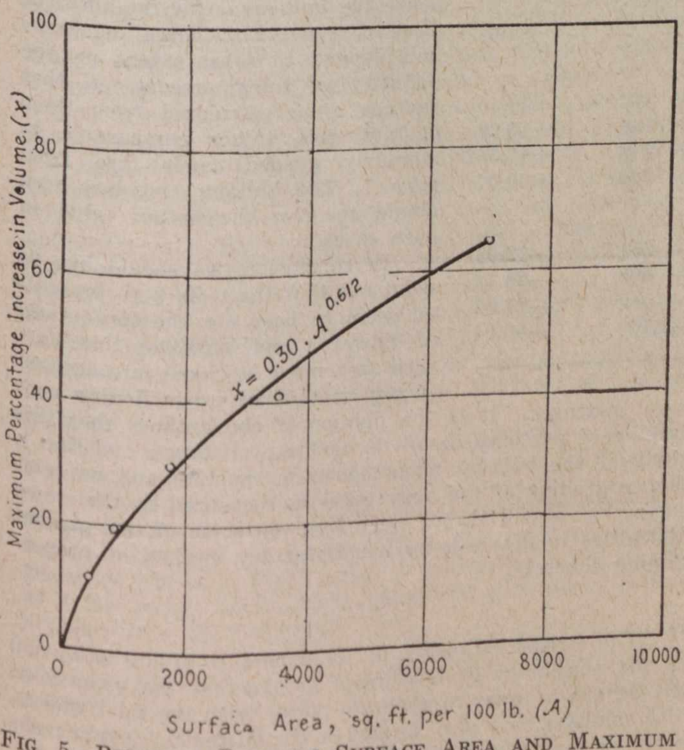

FIG. 5—RELATION BETWEEN SURFACE AREA AND MAXIMUM BULKING FOR SANDS OF ONE SIZE

It is at once apparent that if the laws indicated by Figs. 3 to 6 inclusive are general, the maximum bulking of sand or of a sand-gravel mixture could be determined if its surface area was known; conversely, its surface area could be determined if its percentage of maximum bulking was known. It is evident, however, by the behavior of "one-size" materials that these relationships are not perfectly general, since the large-size particles take no part in the bulking phenomenon.

An experimental study of the limitations within which the conclusions hold have shown that the following is approximately true:—

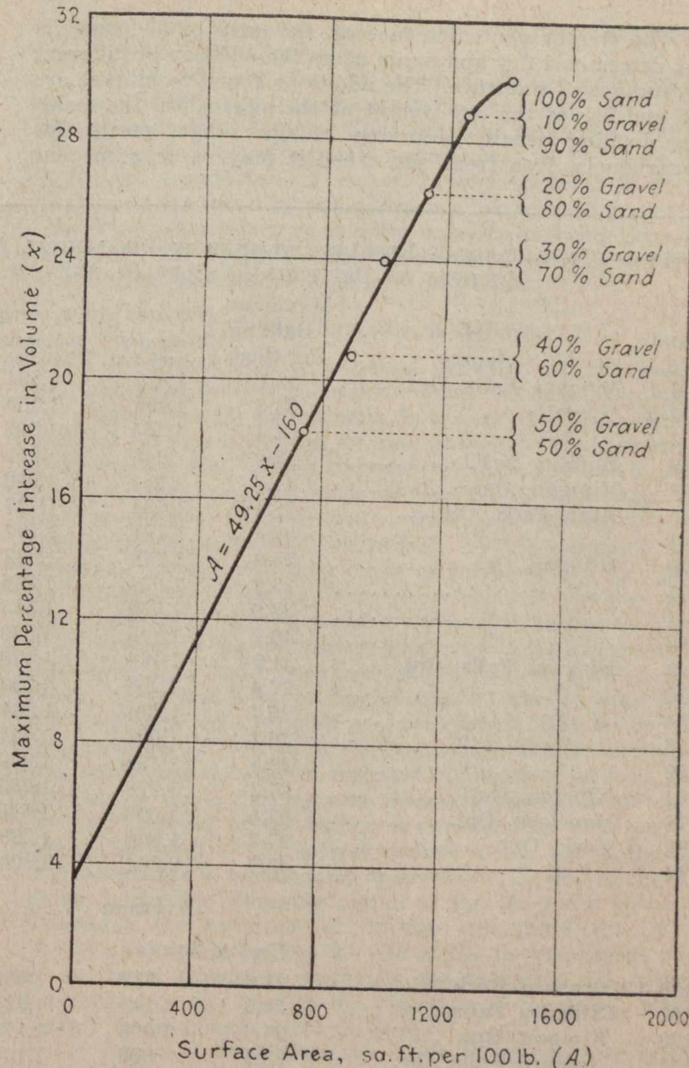

FIG. 6—SURFACE AREA-BULKING RELATION FOR MIXTURES OF SAND AND GRAVEL

1. Extremely coarse sands, sands in which over 60% by weight will not pass the No. 10 sieve, give results higher than those obtained by mechanical analysis. Sands of these characteristics usually have surface areas less than 1,000 sq. ft. per 100 lbs. They will usually be detected immediately by an experienced observer.

2. Extremely fine sands, sands in which 50% passes the No. 65 sieve, give results lower than those obtained by mechanical analysis. The sands are really "one-size" materials, and usually contain a high percentage of silt. They have surface areas in excess of 2,000 sq. ft. per 100 lbs. As in the case of the coarse sands, they can usually be detected by examination.

Silt, when present in excess of 7 or 8%, affects the accuracy of the results to some extent. For percentages lower than this, the effect of the silt is compensated for by the adoption of the point of maximum bulking.

Most sands acceptable for concreting purposes fall within the limits stated. This being so, the relationship between bulking and surface area has two very valuable applications in the science of concrete proportioning:—

(*a*) Knowing the surface area and the moisture content, the changes in volume in the aggregate can be determined and proportions corrected accordingly.

(*b*) Knowing the maximum increase in volume of a sand due to contained moisture, the surface area of that sand is at once obtainable.

While the first of these is important, it is not the subject of this paper and will not be elaborated upon. The second will be taken up at some length.

A method of obtaining the surface area of an aggregate which is both simple and rapid can be based on this relationship between the maximum bulking and surface area.